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“Knowledge is such a treasure which cannot be stolen”

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Indian Standard

**APPLICATION GUIDE FOR
ELECTRICAL RELAYS FOR ac SYSTEMS**

**PART II OVERCURRENT RELAYS FOR
GENERATORS AND MOTORS**

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Indian Standard

APPLICATION GUIDE FOR ELECTRICAL RELAYS FOR ac SYSTEMS

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Indian Standard

APPLICATION GUIDE FOR ELECTRICAL RELAYS FOR ac SYSTEMS

PART II OVERCURRENT RELAYS FOR GENERATORS AND MOTORS

0. FOREWORD

0.1 This Indian Standard (Part II) was adopted by the Indian Standards Institution on 19 December 1966, after the draft finalized by the Relays Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 Modern power systems are designed to provide uninterrupted electrical supply, yet the possibility of failure cannot be ruled out. The protective relays stand watch and in the event of failures, short-circuits or abnormal operating conditions help de-energize the unhealthy section of the power system and restrain interference with the remainder of it and thus limit damage to equipment and ensure safety of personnel. They are also used to indicate the type and location of failure so as to assess the effectiveness of the protective schemes.

0.3 In spite of the many refined protective schemes available today, the overcurrent protection has held its own because of its simplicity and economical cost. Subsequent to the publication of IS: 3231-1965*, it was felt that an application guide for overcurrent relays be prepared so that the system planning engineers may select and apply the overcurrent relays correctly from among the multitude of those available today.

0.4 The features which the protective relays should possess are:

- a) Reliability, that is, to ensure correct action even after long periods of inactivity and also offer repeated operations under severe conditions;
- b) Selectivity, that is, to ensure that only the unhealthy part of the system is disconnected;
- c) Sensitivity, that is, detection of the short-circuit or abnormal operating condition;
- d) Speed to prevent or minimize damage and risk of instability of rotating plant; and

*Specification for electrical relays for power system protection.

- e) Stability, that is, the ability to operate only under those conditions that call for its operation and to remain either passive or biased against operation under all other conditions.

0.5 This guide deals with only those relays which are covered by IS : 3231-1965*. When overcurrent protection for motors is provided in the motor starters reference should be made to IS : 1822-1967† and IS : 3914-1967‡.

0.6 This guide has been prepared mainly to assist protection engineers in application of overcurrent relays installed as a separate unit for generators and motors. Few practical examples have also been included to illustrate the application of these relays, their settings, etc. However, it is emphasized that this guide has been prepared to assist rather than to specify the relay to be used. This guide deals only with the principles of application of overcurrent relays and does not deal with the selection of any particular protective scheme. The actual circuit conditions in all probability may be different from those described here. The examples, even though drawn from actual field applications, should be regarded as mere illustration of one or the other point.

0.7 In the preparation of this guide considerable assistance has been derived from several published books and from manufacturers' trade literature. Assistance has also been rendered by State Electricity Boards in collecting actual examples.

0.8 This guide is one of the series of Indian Standard application guides for electrical relays for ac systems. The other guides in this series are:

IS : 3638-1966 Application guide for gas-operated relays

IS : 3842 (Part I)-1967 Application guide for electrical relays for ac systems: Part I Overcurrent relays for feeders and transformers

IS : 3842 (Part III)-1966 Application guide for electrical relays for ac systems: Part III Phase unbalance relays including negative phase sequence relays

IS : 3842 (Part IV)-1966 Application guide for electrical relays for ac systems: Part IV Thermal relays

*Specification for electrical relays for power system protection.

†Specification for ac motor starters of voltage not exceeding 1 000 volts (first revision)

‡Code of practice for selection of ac induction motor starters (voltage not exceeding 1 000 volts).

1. SCOPE

1.1 This guide deals with application of overcurrent relays for ac systems covered by IS : 3231-1965* for generators and motors.

1.2 This guide does not cover:

- a) the principles of system design and system protection, and
- b) application of such relays which form an integral part of a motor starter.

2. TERMINOLOGY

2.1 For the purpose of this guide, the definitions given in IS : 1885 (Part IX)-1966† and Part I of this guide shall apply.

3. OVERCURRENT RELAYS FOR GENERATORS

3.1 General

3.1.1 Overcurrent relays have a limited application in the protection schemes for generators as they cannot provide as good a protection for the generators as differential relays. They are principally applied to provide back-up protection for sustained external faults, that is, on the bus-bars or on the feeders. However, they also act as back-up to the differential protection on internal faults where bus-bars can feed into the faults.

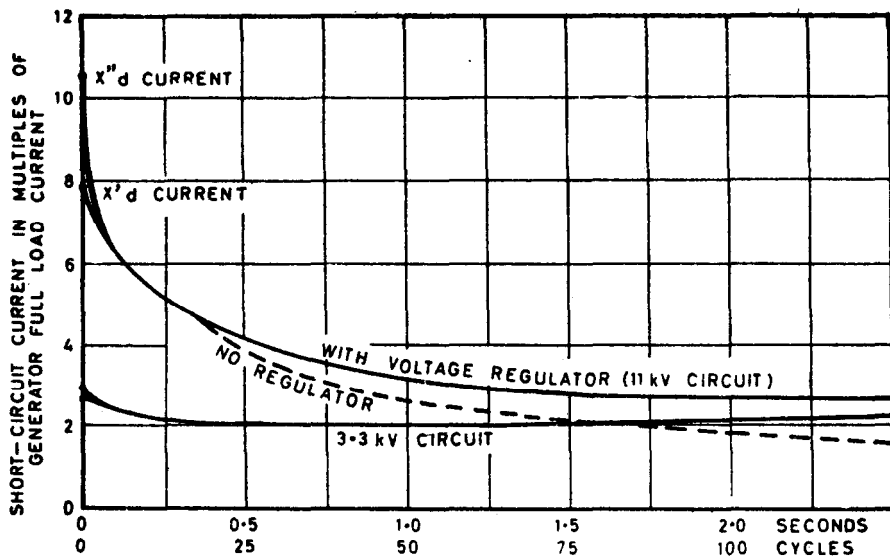
3.1.2 Simple inverse definite minimum time-lag (IDMTL) overcurrent relays as described for the protection of feeders and transformers are, in general, unsatisfactory for phase-to-earth fault back-up protection because certain methods of earthing of the generator, that is, distribution transformer or voltage transformer earthing limit the maximum available earth fault current to a value below the normal settings of inverse time relays.

3.1.3 When used as a back-up protection for sustained external phase faults, the selection of the relay and their settings must be very carefully considered. The synchronous impedance (which will vary anywhere between 110 to 250 percent), limits the sustained fault current fed by the generators to about the same as, or less than, the rated load current. Due to the rapid decrement of the short-circuit current (see Fig. 1), the relay should be so set that it allows sufficient margin over the rated overload capacity of the machine, and, at the same time, is capable of operating at the short-circuit value at full decrement.

3.1.4 With an automatic voltage regulator used with machine the sustained fault current would be higher than the maximum load current. In such cases, a simple attracted armature electromagnetic type of overcurrent

*Specification for electrical relays for power system protection.

†Electrotechnical vocabulary: Part IX Electrical relays.



NOTE — Voltage regulator in use and exciter ceiling voltage limited to 1.35 pu.

FIG. 1 A TYPICAL SHORT-CIRCUIT DECREMENT CURVE

relay in conjunction with a definite time delay relay is used to protect the generator. The overcurrent setting may be about 125 to 150 percent of the full load current of the generator and the definite timing may be between 3 to 6 seconds, depending on the individual case. Sometimes three such units are incorporated, one in each phase of the generator; sometimes only one relay in any one phase, along with a phase unbalance relay is used. Instead of the attracted armature relay with definite time delay, an IDMTL relay may also be used for a generator with an automatic voltage regulator, and is set at about 120 percent of the full load current of the generator.

3.1.5 As a back-up for the unit protection of the generator in case of internal phase faults, the setting mentioned earlier is quite satisfactory in cases where the bus-bar fault MVA is appreciably greater than the sustained fault MVA fed by the machine. As a protection against such faults, it is necessary to de-excite the machine by the overcurrent relay.

3.1.6 Where generators are not fitted with automatic voltage regulators, the sustained fault currents fed by the generator on an external fault may be less than the maximum load current. In these cases, a voltage restraint or a voltage controlled inverse time provides the necessary discrimination between generator feeding the normal loads, and the generator feeding sustained external fault currents. These are dealt with in 3.2 and 3.3.

3.1.7 Overcurrent relays continue to be used to prevent overheating of the generator rotors on account of prolonged unbalanced currents. These are described in Part III of this guide. Overcurrent relays interlocked with the unit protection are also available where the cost of providing current transformers on both sides of the circuit-breaker is not justified, for example, when air blast circuit-breakers are used (*see also 3.4*).

3.2 Overcurrent Relay with Voltage Restraint

3.2.1 It is an induction disc relay with a voltage restraint circuit which restrains the action of the current element. The restraining coil distinguishes between a normal operating and a short-circuit condition by the change of voltage even if the magnitudes of currents in the two conditions are equal. The restraining effect is reduced as the voltage drops whenever there is a short-circuit and the overcurrent element then operates. In Fig. 2 time current characteristics of this relay are shown and it may be seen that the sensitivity and speed increase as the voltage restraint decreases. The curves for intermediate values for voltage restraint fall inside the two extremes shown in Fig. 2 but it is better to obtain them from the manufacturer. Like all other induction overcurrent relays, current taps and time dial arrangement are also provided.

3.2.2 It is recommended that current setting of between 200 to 250 percent of the generator rating at rated voltage is selected if there is a continuously acting automatic voltage regulator. The current setting is reduced to 150 to 200 percent if there is no continuously acting automatic voltage regulator. The time multiplier scale is chosen for the zero volt restraint time current characteristic for three-phase faults close to the bus-bar. If the system connection is such that a three-phase fault on or close to the bus-bar did not produce zero volt restraint on the relay, it is necessary to use an appropriate time current curve for voltage restraint between zero and 115 volts. In Fig. 3 is shown a generator connected to the bus-bar which is feeding a radial circuit. Ordinarily, it is quite sufficient to obtain the time and current settings of the relays at *C*, *B* and *A*, allowing for the co-ordinating time interval of 0.4 second. The time of operation of the back-up relay at *A* may, however, be reduced if the effect of the decaying current on the performance of the relay at *B* and *A* is calculated. A typical decrement curve is shown in Fig. 1.

3.2.3 The calculation of the behaviour of relays at *A* and *B* on decaying fault current, is done by trial and error method. For details of this method reference is invited to 6.4.3.1 of IS : 3842 (Part I)-1967*. To start with, the time of operation of relay at *B* is assumed. Then the average current from time zero to the time of operation of relay at *B* is

*Application guide for electrical relays for ac systems: Part I Overcurrent relays for feeders and transformers

obtained from the decrement curve by step-by-step method. If the average current so obtained is insufficient to close the contacts of the relay at *B*, the time of operation of this relay is accordingly raised and the step-by-step method is continued until a satisfactory answer is obtained. The next step is to select a time dial setting for the relay at *A* to make it selective with relay at *B*. As may be seen from Fig. 3, that by taking account of the decrement of the fault current, the operation of the generator relay can be made faster by about half a second.

3.3 Voltage Controlled Overcurrent Relays

3.3.1 This relay has an induction disc overcurrent element with time delay operation and an undervoltage element. The two elements are so connected that undervoltage element on operation modifies the characteristic of the inverse time element, that is, the operating current is reduced below full load current of the machine and the operating time curve is changed to

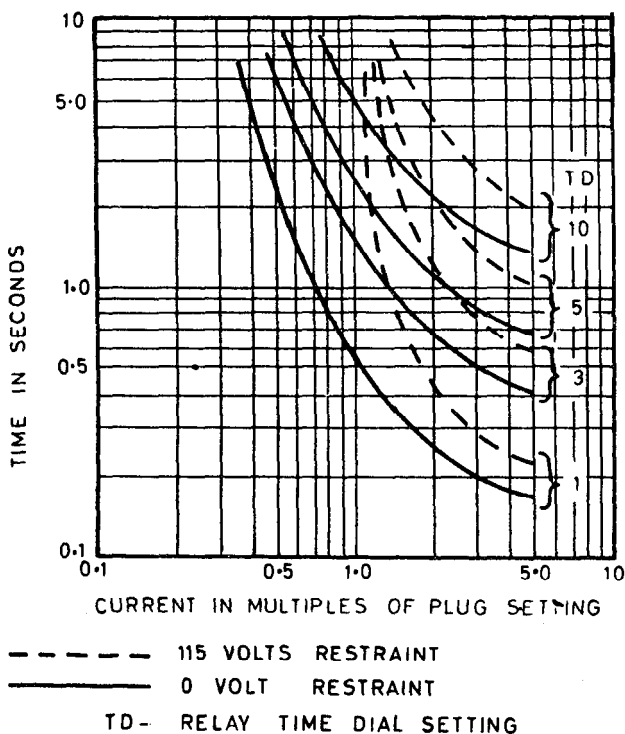


FIG. 2 TIME-CURRENT CHARACTERISTIC CURVES OF OVERCURRENT RELAY WITH VOLTAGE RESTRAINT FOR GENERATOR PROTECTION

the standard curve (see IS : 3231-1965*) to enable grading under fault conditions to take place more easily. The overcurrent element may be provided with any of the inverse characteristics described earlier, with current taps and time dial adjustments. The relay may be set to operate on less than full load current when the voltage falls below a predetermined value.

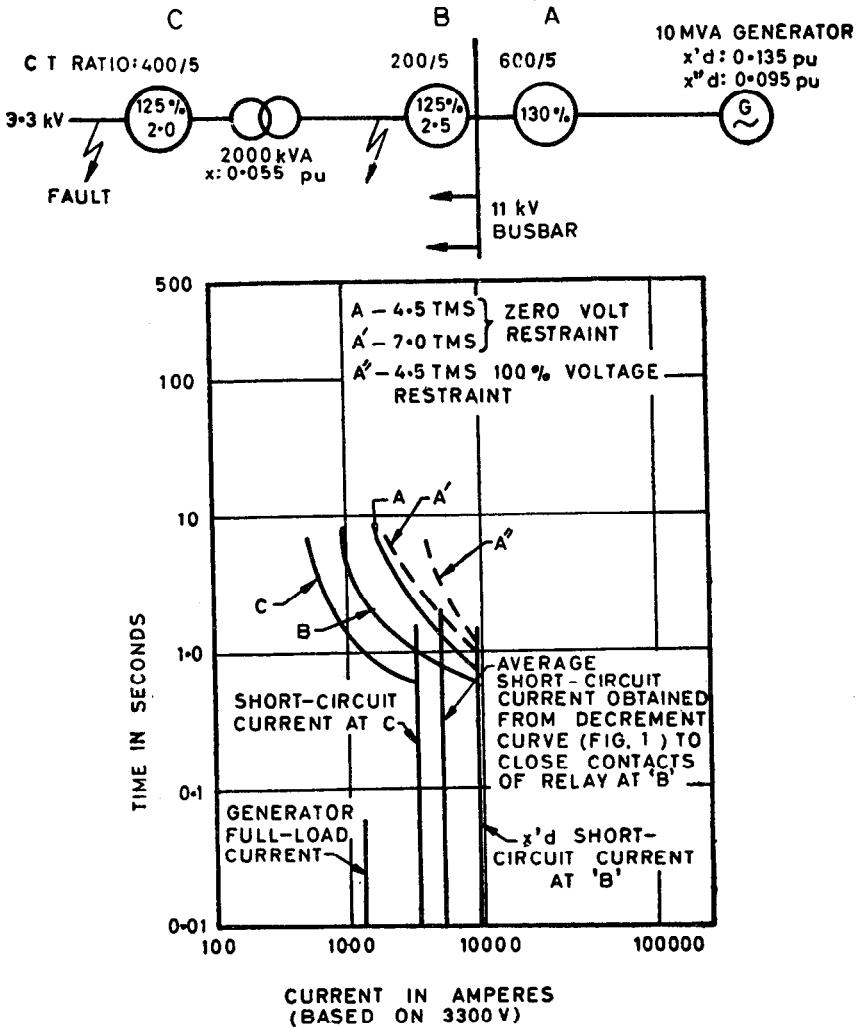


FIG. 3 CO-ORDINATED TIME-CURRENT CURVES OF GENERATOR OVERCURRENT RELAYS

*Specification for electrical relays for power system protection.

3.3.2 This relay is a combination of undervoltage and overcurrent units. The undervoltage relay operates instantaneously but the time current characteristics of the overcurrent unit is similar to that of an IDMTL relay. Figure 4 shows the typical characteristics of a voltage controlled overcurrent relay. Curve 1 gives the time-current characteristics for overload conditions and curve 2 gives the same characteristics for short-circuit conditions, that is, when the voltage falls on account of the short-circuit.

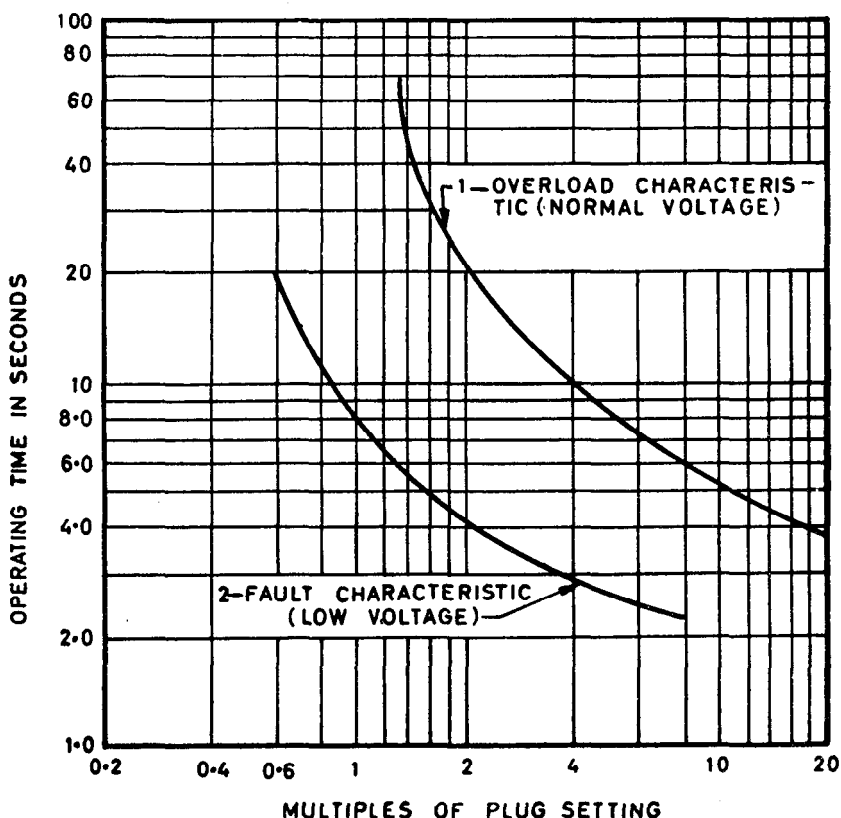


FIG. 4 CHARACTERISTICS OF VOLTAGE CONTROLLED OVERCURRENT RELAY

3.3.3 Instantaneous undervoltage element controls operation of the induction overcurrent element and should be set to operate at a voltage above the minimum value expected under the fault conditions likely to be met on the system. The overcurrent unit is set to ride over the normal load swings. It should be checked that the voltage at the generator terminals

is sufficient to operate the undervoltage element for all external faults for which the overcurrent relay should back-up. This is particularly relevant for a generator-transformer unit connection because the impedance of the transformer together with the effect of automatic voltage regulator may not produce sufficient voltage drop (the voltage being taken from the generator voltage transformer) for a fault just outside the transformer secondary terminals.

3.3.4 The operating characteristics of this relay do not change with the voltage as it does in the case of overcurrent relays with voltage restraint between zero to rated voltage. On the contrary the relay operates or not according as the voltage is below or above the setting.

3.3.5 An example of application of voltage controlled overcurrent relay with definite time characteristic is given in Appendix A.

3.4 Interlocked Overcurrent Protection

3.4.1 Interlocked overcurrent protection is required if all the protective current transformers are located on one side of the circuit-breaker only as shown in Fig. 5. A fault occurring between the circuit-breaker contacts and the current transformers cannot be cleared completely either by the bus-bar protection or the differential protection of the generator. Figure 5 shows two possible locations of the current transformers. A fault at point *A* is continued to be fed by the generator even after the circuit-breaker has been opened by bus-bar protection. Similarly, a fault at *B*, although detected by the generator differential protection, is not cleared by the resultant opening of the circuit-breaker.

3.4.2 A special overcurrent relay interlocked with either of them depending on the location of the current transformers, is used to isolate the fault completely. An overcurrent relay with a sufficient time delay setting is interlocked with the appropriate protection, that is, bus-bar protection or the differential protection. For a fault at *A*, the tripping relay associated with the bus-bar protection closes a normally open contact to complete the circuit of the shading winding of the overcurrent relay allowing the latter to shut down the generator. For a fault at *B*, the tripping relay of the differential protection completes the circuit of the shading winding of the overcurrent relay which in turn operates the bus-bar protection tripping relay to clear the faulty section..

3.4.3 Normally these relays are provided with a current setting of about 75 percent of rated current for three-phase faults for a fault at *A*. The operating time of the relay is about 0.4 second at 5 times the current setting. However, the relay settings for fault at *B* should be carefully selected after ascertaining the fault in-feed from the bus-bar side.

3.4.4 The relay usually employs an induction disc pattern construction having a summation type of main electromagnet winding (see Fig. 6). The

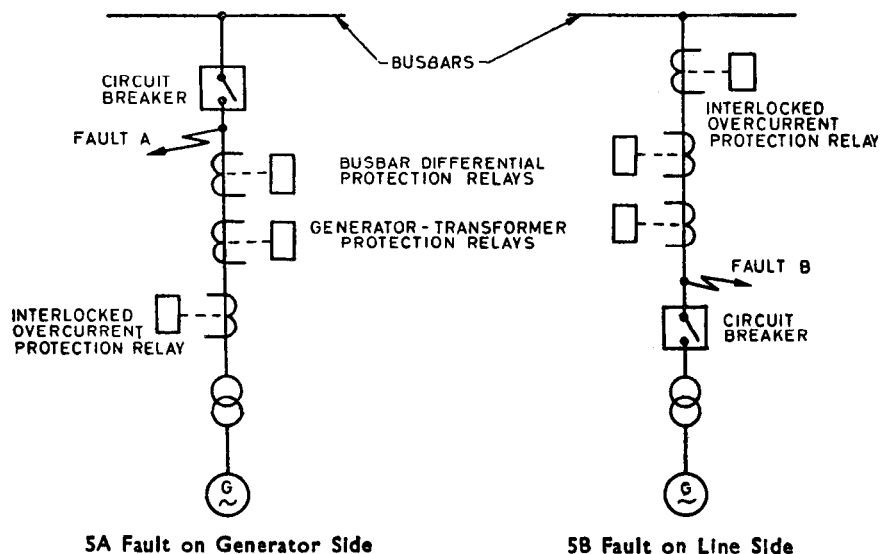


FIG. 5 INTERLOCKED OVERCURRENT PROTECTION

shading circuit consists of a wound shading coil, a saturating choke and a capacitance. The choke is designed so that it starts to saturate just below the setting current of the relay. This feature gives the relay a high torque near the setting and definite minimum time characteristic. The shading circuit is closed by a normally open contact of the bus-bar or generator differential protection, as the case may be, to make the relay operative.

3.4.5 Instantaneous highset overcurrent relays are used to give high speed tripping on phase faults. The current setting provided is normally continuously variable and the relay is set above the maximum starting current. Relays with low transient over-reach may be used which can be set very close to the maximum starting current. Typical settings are 800 to 1 600 percent of rated current transformer secondary current.

3.5 Settings and Co-ordination of Overcurrent Relays

3.5.1 IDMTL relays when used are given a setting between 125 to 200 percent of the rated current depending upon the overload characteristics of the generator. These relays are used for back-up protection only when continuously acting automatic voltage regulators are provided. Settings depend to a large extent on whether operation on loss of field is required or not. If it is desired that the overcurrent relay should not operate on loss of field then it is necessary to select the current settings such

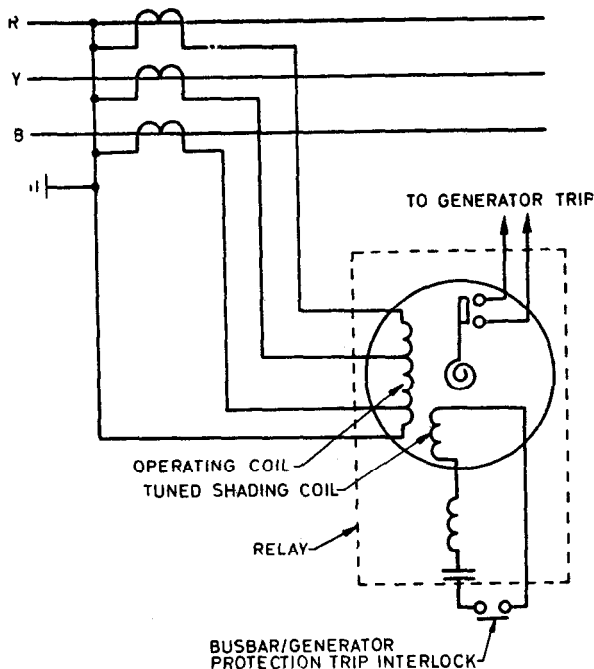


FIG. 6 INTERLOCKED OVERCURRENT PROTECTION RELAY

that it will not operate on the excitation current drawn by the generator from the system. The grading of these relays with similar relays on the feeders may be worked out on the same principle as outlined in Part I of this guide.

3.5.2 Voltage controlled and voltage restraint overcurrent relays are normally provided on machines which are not fitted with automatic voltage regulators and where back-up protection with an overcurrent relay is difficult because the synchronous impedance limits the three-phase fault current on sustained faults to about the same or even less than the maximum load current. When these relays are used, it is preferable to use similar relays on the bus-bars for the outgoing feeders so that proper and easy grading may be ensured for feeder faults. Where a voltage restraint type of relay is used, the current-time characteristic of the relay is affected by the voltage, making it difficult to co-ordinate with other relays on the feeders. Unless carefully applied, such relays may also provide grading difficulty when distance relays are used for the feeders. Zone 2 and zone 3 operating time of the distance relays should be less than the operating time of the voltage restraint relays under various fault conditions.

3.5.3 Voltage restraint and voltage controlled relays can mal-operate on inadvertent loss of voltage supply. In order to prevent false tripping on load, fuse failure relays may be used to supervise the voltage transformer secondary fuses.

4. OVERCURRENT RELAYS FOR MOTORS

4.1 The guiding factor for overcurrent relays for motors is that they should not operate due to the momentary excess currents during the normal starting condition but they should provide adequate protection to the motor during abnormal starting conditions as well as during sustained overloads in running conditions.

4.2 Usually there are two types of overcurrent relays used for the protection of motors, namely:

- a) Thermal relays (*see* IS : 1822-1967* for relays forming an integral part of motor starters and IS : 3231-1965† for relays installed separately), and
- b) Induction type relays (*see* IS : 3231-1965†).

4.3 Instantaneous overcurrent relays having a setting range of about 200 to 800 percent or 400 to 1 600 percent of current transformer secondary current may be used to provide protection against phase faults on the motors. The exact setting of such relays is normally determined at the time of commissioning. The setting should be high enough to prevent mal-operation under motor starting conditions.

4.4 For overload protection of motors, it is common to use thermal relays [*see* IS : 3842 (Part IV) - 1966‡]. However, in certain cases, overcurrent relays with very inverse and extremely inverse characteristics may also be used. In some applications, both thermal and induction type overcurrent relays are used to provide complete overload protection to motors, both under light overloads and heavy overloads. One such example is shown in Fig. 7. The type of relay required depends on motor starting and thermal withstand characteristic [*see* IS : 3842 (Part IV) - 1966‡].

4.5 In addition to thermal relays, long time induction disc relays are also used for motor protection. However, thermal protection has an advantage over long time induction disc relays because of the spread between hot and cold characteristics. This allows a tripping time of less than the starting time when a hot motor is stalled, so that separate stalling protection is less likely to be necessary. This, of course, depends upon the starting conditions of the motor and applies when the motors are not expected to start when hot, that is, thermal relay characteristics permitting the motor to start only when cold. Details regarding application of thermal relays are covered in Part IV of this guide.

*Specification for ac motor starters of voltage not exceeding 1 000 volts (*first revision*).

†Specification for electrical relays for power system protection.

‡Application guide for electrical relays for ac systems: Part IV Thermal relays.

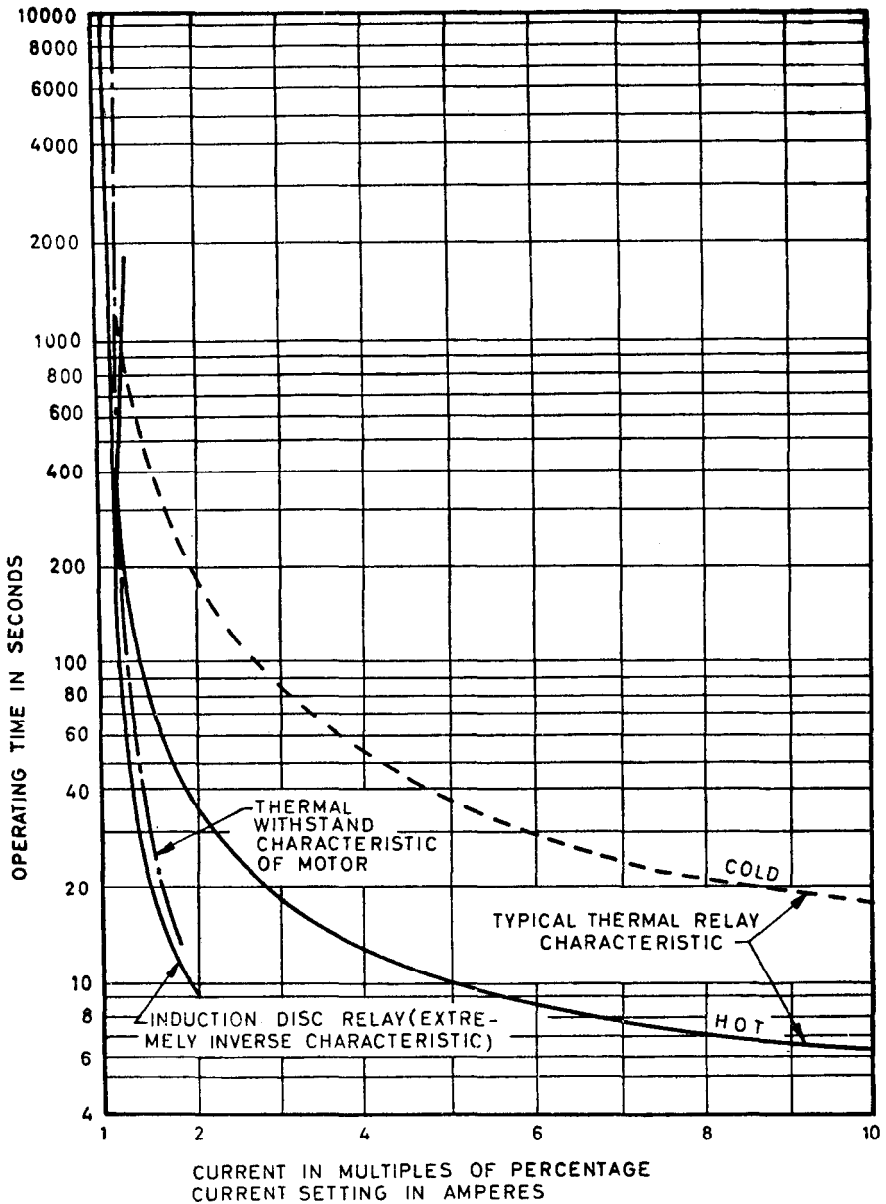


FIG. 7 PROTECTION OF A 480 kW, 3.3 kV MOTOR USING THERMAL AND INDUCTION DISC RELAYS

4.6 Instantaneous earth fault protection having a setting of about 20 percent of rated current transformer secondary current may also be provided on motors which are connected to systems earthed through a resistance or reactance. Such relays may be operated in series with a stabilizing resistance to prevent mal-operation under starting.

A P P E N D I X A

(*Clause 3.3.5*)

EXAMPLE SHOWING AN APPLICATION OF VOLTAGE CONTROLLED OVERCURRENT RELAY WITH DEFINITE TIME CHARACTERISTIC

Rated full load generator current at 11 kV	= 7 050 A
Current transformer ratio	= 8 000/5 = 1 600
Relay drop-out coefficient	= 0.85
Current setting of the relay	= $\frac{1.25 \times 7\,050}{0.85 \times 1\,600} = 6.5 \text{ A},$

where 1.25 is the reliability factor.

The voltage setting has been made equal to 70 percent of minimum operating voltage.

$$\text{Voltage setting} = \frac{0.7 \times 11 \times 10^3}{100} = 77 \text{ volts},$$

where 100 is the voltage transformer ratio and 11 000 volts is the rated voltage.

As the protection is of definite time, it is set to operate after a time lag of 4 seconds.

After setting the relays as above, a check has also been made regarding the response on three-phase fault at 220 kV bus-bar. It may be mentioned here that in between the 11 kV generator bus-bar and the 220 kV bus-bar, there is 11/220 kV unit transformer.

$$\begin{aligned} \text{Fault current on 11 kV side for a fault} \\ \text{on 220 kV bus-bar} &= 20\,800 \text{ A} \\ \text{Current sensitivity} &= \frac{20\,800}{6.5 \times 1\,600} = 2, \end{aligned}$$

where 6.5 is the current setting and 1 600 is the current transformer ratio.

$$\begin{aligned} \text{Voltage at 11 kV side for a three-phase} \\ \text{fault at 220 kV bus-bar} &= 4.3 \text{ kV} \\ \text{Voltage sensitivity} &= \frac{77 \times 100}{4.3 \times 10^3} = 1.8 \end{aligned}$$

This shows that both the current element as well as the voltage element will operate positively for a fault on 220 kV bus-bar.

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Institution of Engineers (India) Building 1332 Shivaji Nagar, PUNE 411005 32 36 35

*Sales Office is at 5 Chowringhee Approach, P.O. Princep Street, CALCUTTA 700072 27 10 85

†Sales Office is at Novelty Chambers, Grant Road, MUMBAI 400007 309 65 28

‡Sales Office is at 'F' Block, Unity Building, Narashimaraja Square, BANGALORE 560002 222 39 71